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TECHNICAL MEMORANDUM

Date: **August 19, 2020**

To: **Emily Anderson, Alaska Program Director, Wild Salmon Center**

From: **André Sobolewski, Clear Coast Consulting, Inc**

Subject: **Review of water treatment plants proposed in FEIS for Pebble Project**

I was retained by the Wild Salmon Center to review documents relating to water treatment in the Final Environmental Impact Statement for the proposed Pebble Project. I reviewed the FEIS and its appendices, building on previous reviews of the water treatment system proposed the Draft and Pre-Final Environmental Impact Statement, including several Requests for Information (RFI021a-k) released after the PFEIS was issued.

1 Key Findings

Given the sensitivity of the receiving environment, the water treatment scheme proposed in the FEIS is unacceptably risky. It will fail to meet stringent water quality criteria for a number of contaminants, including selenium, to which productive ecosystems downstream from the proposed Pebble Mine are especially sensitive.

The proposed water treatment plants (WTPs) are large, complex and, contrary to the USACoE assertion, do not use industry standards and proven processes and technologies. On the contrary, the chemical process proposed for selenium removal is unproven, will be ineffective and result in exceedances of ADEC standards during mine operation. The treatment performance predicted for other contaminant is overly optimistic: there is a high risk that WTPs will not meet stringent discharge criteria. Worse, these claimed performance are not supported by testwork, published literature or case studies. It is unacceptable that a treatment system proposed in an EIS – one that uses unproven technology – should be accepted on faith.

Several risks associated with the proposed treatment systems have been identified, including the risk that Northern Dynasty Minerals does not have adequate resources to develop these complex treatment plants in time for operation. Most worrisome is the risk that the company will default on its obligation to treat water in perpetuity.

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In conclusion, the water treatment systems presented in the FEIS are complex and unproven and are predicted to discharge non-compliant water that will impact sensitive ecosystems downstream from the proposed mine. The treatment scheme proposed by the USACoE in the FEIS should be flatly rejected.

2 Qualifications and Professional Expertise

I am an environmental consultant with a PhD in Biology and 30 years of professional experience (résumé appended). I have participated in nearly twenty Environmental Impact Assessments and have developed a guidance document for assessing impacts of planned mines for the Yukon government (through the Yukon Environmental and Socio-economic Board, YESAB). I have participated in nearly 100 mining-related projects, principally in the development or evaluation of water treatment systems. Most of my work involved the evaluation and/or design of water treatment systems at mining operations. For example, I participated in the evaluation of requirements to upgrade the water treatment systems at the Yanacocha mining complex, which include two reverse osmosis plants, a project comparable in scope and scale to the Pebble Project. My clients include natural resources industry, government, First Nations and non-government organizations. I have also provided expert technical opinions in legal cases. This background qualifies me to provide an unbiased expert technical opinion on the proposed water treatment plants for the Pebble Project.

3 Treatment System Design

The USACoE description of the water treatment plants (WTPs) proposed for this project (FEIS Appendix N – Project Description) is beautifully written. In fact, it is among the best descriptions I have ever read. However, I am disturbed by several aspects of this treatment system design.

USACoE states in the FEIS Appendix N – Project Description:

> *WTP #2 will treat water from the main WMP with treatment plant processes commonly used in the mining industry around the world.*

The necessity of this particular design is never rationalized, save for the complicated process to remove sulfate by membrane filtration, calcium precipitation and salt evaporation. None of Chapter 4: Environmental Consequences – Section 4.18. Water and Sediment Quality, Appendix N – Project Description, or Appendix K - Section 4.18. Water and Sediment Quality present a single statement explaining how the treatment system will remove any individual analyte to an acceptable level. A statement like:

> *The concentration of* x *contaminant will be decreased to* xxx *mg/L, which is below the Alaska Department of Environmental Conservation (ADEC) criteria. This prediction is supported by [testwork, case study, industry standard].*

This makes it nearly impossible to evaluate "fitness-for-purpose" of any component of the treatment system specified by the USACoE, and to assess the validity of their assertions. In my own assessment, I find that there are questionable choices and decisions made in the design of the proposed treatment system. For example, the first step in the common treatment process – the addition of permanganate for metal oxidation, followed by their precipitation with ferric chloride – is the correct process for removing arsenic, but it is the opposite process for removing selenium. In the latter case, a reductant is required (such as zinc dust), not an oxidant like permanganate. In fact, oxidation *will prevent* the reaction that removes selenium. In this case, arsenic is expected to be removed in this first step of the treatment process, but not selenium, contrary to the claim by the USACoE.

In all my previous assignments to conduct or review an Impact Assessment, including work in Canada, USA, Panama, Peru and Armenia, I have never seen a treatment system being presented without justification of its ability to meet mandated effluent quality. Typically, an EIS presents a table of analytes in contact water, denotes predicted exceedances, proposes a treatment processes to decrease their concentrations and demonstrates their suitability in removing contaminants below mandated discharge concentrations. The complete absence of such justification for the treatment system proposed by the USACoE is unacceptable. Specifically, the assertion of "*processes commonly used in the mining industry*" cannot be tested because it is not justified in relation to the treatment of specific contaminants.

USACoE makes a grievously flawed statement in the Chapter 5.0 – Mitigation, Table 5-2:

> *Additional modeling and pilot plant testing would further evaluate the feasibility of WTP processes, assess maintenance requirements, reduce uncertainties, and refine discharge water quality predictions.*

NO! There can be no doubts about the feasibility of a treatment process or technology proposed in the EIS. If there is, then this process or technology should be discarded in favor of one that is known to be feasible. This is what is understood by adopting Best Management Practices and Industry Standards. The Pebble Project is not a place to experiment: there's too much risk for that to be permitted. Any technology presented in the FEIS must be established and should never be in doubt.

In the absence of any analysis of the suitability of the proposed treatment system to meet ADEC criteria, I conducted my own. For this assessment, I relied on data provided in: Predicted Water Quality Inflows for WTPs in Operations and various phases of Closure. Our own independent analysis cast doubt on some of the predicted inflow concentrations for certain analytes, but these uncertainties were merely noted, not accounted for. As with any design work, the 90th percentile concentrations were used to evaluate the suitability of the proposed treatment process.

For this analysis, I used the proposed WTP #2 for mine operations (Figure 1), as it is among the most comprehensive WTP proposed for this project (WTP #3 also comprises an evaporator/crystallizer unit). This treatment system shares many components with WTP #1 and WTP#3 and any analysis of WTP #2 will readily apply to these other treatment plants.

Analytes in WTP #2 influent requiring treatment were drawn from Table K4.18-5-11, as noted for those predicted to exceed ADEC criteria during mine operations (Table 1). These analytes are similar, with some variation, to those found in inflows to other treatment plants during operations and closure.

Table 1. Analytes that exceed water quality criteria.

Analyte	90th Percentile concentration mg/L
Sulfate	1,747
Antimony	0.0645
Arsenic	0.0869
Beryllium	0.0372
Boron	0.754
Cadmium	0.0179
Cobalt	0.0515
Copper	0.0100
Lead	0.0372
Manganese	1.85
Mercury	0.000262
Molybdenum	3.65
Nickel	0.115
Selenium	0.0397
Silver	0.0031
Zinc	2.61

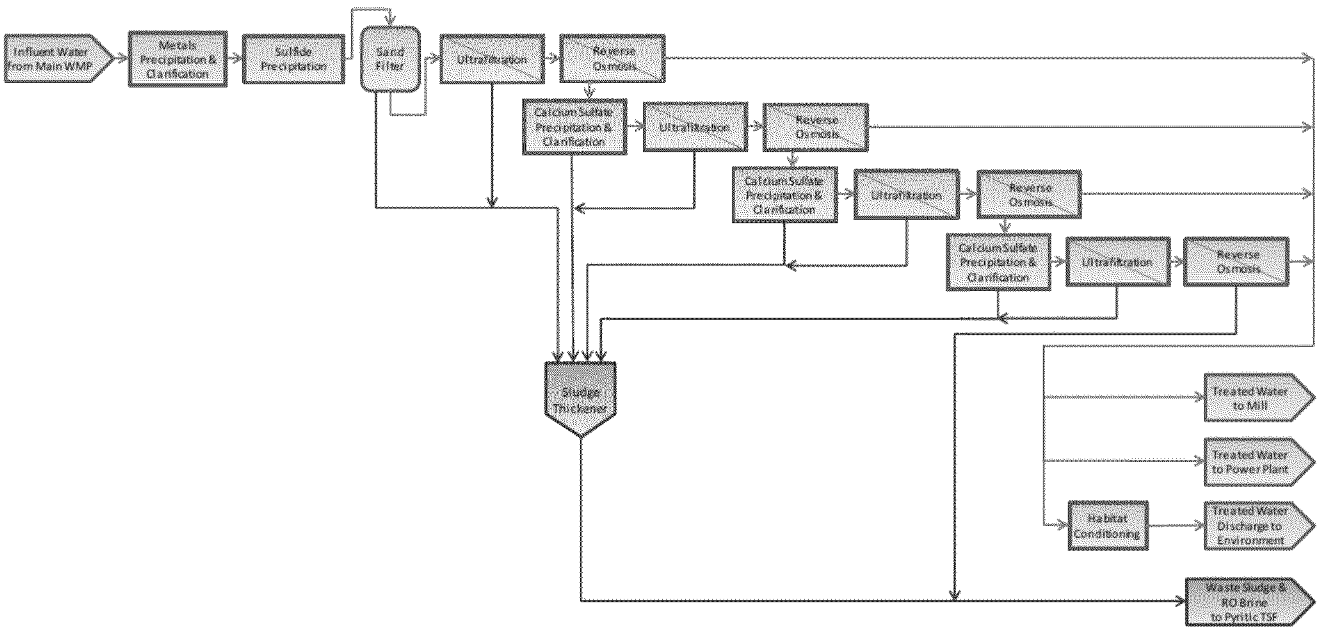

Figure 1. Water Treatment Plant #2 - Operations Phase. Taken from USACoE FEIS Appendix N – Project Description

The first step in the treatment process – permanganate oxidation and ferrihydrite precipitation – is effective in removing arsenic and manganese and is widely used. Depending on treatment conditions (pH, ORP), molybdenum will also be removed to acceptable levels, as evident by the treatment plant at the closed Brenda Mine (Aubé and Stroiazzo, 2000) and at Coldelco's El Teniente Mine (Aubé and Vergara, 2010).

The oxidative precipitation of manganese into a dioxide (pyrolusite) will also remove trace metals, including cadmium, cobalt, copper, lead and zinc. However, its starting concentrations are relatively low and it is difficult to predict how much trace metal concentrations will be decreased.

Permanganate oxidation, followed by ferrihydrite precipitation is reported to remove selenium (RFI 021e Addendum, 2019), but this is incorrect. Ferrihydrite precipitate the *partially-reduced* selenite (SeO_3^{2-}), not the *full oxidized* selenate (SeO_4^{2-}). Thus, an initial reductive step is required to reduce the unreactive selenate to selenite, like the addition of zinc dust (Alberta Environment, 2005), and to remove it via iron co-precipitation. The latter reaction is effective in decreasing high inflow concentrations of selenium, but it can only decrease its levels to ~0.020 mg/L. An additional step is necessary to decrease its concentration < 0.005 mg/L.

Iron co-precipitation can remove several metals; however, their concentrations will not be decreased low enough to meet stringent water quality criteria (MEND, 2014). A High-Density Sludge (HDS) system is required to decrease metals to trace levels, but this is not what is proposed at Pebble. Therefore, additional treatment will be required to decrease the concentration of most metals to levels acceptable for discharge.

Several metals form highly insoluble sulfides and nominally will be removed to below ADEC criteria in the sulfide precipitation stage. These include antimony, cadmium, cobalt, copper, lead, mercury, nickel, silver and zinc. Sulfide precipitation is expected to be highly effective, but some uncertainties remain. It is well known that metals like zinc can form colloidal sulfides that remain in solution (Gammons et al., 2000; Jarvis et al., 2015). Potentially, these colloids will be retained in the membrane filtration units, either in sludge of the UF unit or in retentate (or reject) in the reverse osmosis units. Either way, it is probable that colloidal zinc sulfides will be returned to the Pyritic TSF, where they will re-dissolve and return to the water circuit, resulting in gradually increasing concentrations. This potential problem cannot be resolved without testwork on actual mine water, nor is it easily resolved after it is detected during mine operation.

Mercury removal can nominally occur during the sulfide precipitation step. However, it is difficult to decrease its concentrations to exceedingly stringent water quality standards unless specialty chemicals are used. The conditions for its effective removal can be determined during testwork, although this usually involves considerable R&D (Blythe and Owens, 2008). but such a process can easily be bolted on after the sulfide precipitation step.

Selenium is proposed to be removed as a selenide via precipitation with sulfide. This reaction is technically possible and has been demonstrated in the laboratory, but it requires conditions that are not met in a mining environment (low redox potential, high sulfide concentrations, etc). To my knowledge, this process has never been used in a commercial application, and certainly never at a large-scale mining operation. Several specialists who know or investigated this process[1] have confirmed that it is impractical for selenium removal from mine water.

In the Draft EIS, a biological treatment process was proposed for selenium removal. This is widely recognized at the current state-of-the-art and established industry practice (Alberta Environment 2005; MEND, 2014; NAMC 2010, 2013, 2020). Its rejection in favour of the unproven and untested sulfide precipitation process is a retrenchment of established norms and industry practices. **This process for selenium removal proposed by the USACoE goes against current practice and is not supported by any published experimental design or case study.** The literature presented in RFI 021h to support their process is outdated and has been superseded by the more recent publications cited above. Moreover, an extensive review and testing of selenium treatment technologies by Teck Coal concluded that sulfide precipitation is not a viable process[2] and that biological treatment is the only process that produces compliant effluents at their operations (Teck 2014). **Thus, the assertion by the USACoE that "*WTP #2 will treat water from the main WMP with treatment plant processes commonly used in the mining industry around the world*" is false**.

In the absence of chemical precipitation, selenium will be removed in the WTP by membrane filtration, either via nanofiltration or reverse osmosis. Given that selenium-containing brine generated by membrane filtration will be discharged into the Pyritic TSF, there is a concern that its concentration will build up in mine water because WTP #2 → Brine → Pyritic TSF → Main WMP → WTP #2 is a closed-loop circuit. This concern was acknowledged by Pebble and was analyzed through a water balance and water chemistry model (Knight Piésold, 2019). I reviewed this model.

The KP model assumes incorrectly that all the incoming selenium will be removed by chemical precipitation: its predicated concentrations in brine was 0.006 mg/L (HDR 2019a, Table 3, as indicated in Knight Piésold 2019, Table D3.1). I have already argued that chemical precipitation will not work and assumed instead that selenium will be removed via membrane filtration in WTP #1 and #2. We previously showed that membrane filtration will remove 90% of influent selenium (Zamzow et al, 2019). I also estimated that an additional 5% of selenium in brine will be removed via co-precipitation with gypsum in the sulfate removal stage[3].

[1] Dr. Dirk Wallschläger, School of the Environment/Chemistry, Trent University, Canada; dr.ir. J (Jan) Weijma, Environmental Technology Group, Wageningen University and Research; Drs Stephane Brienne, Section Leader, Environmental Technology, and Alberto Gonzalez, Principal Metallurgist, Applied Research and Technology, Teck Resources Limited.

[2] Drs Stephane Brienne and Alberto Gonzalez, Teck Resources Limited. Personal Communication.

[3] This removal rate was observed by Dr. Stephen Day, SRK Consultants. Personal Communication.

From these removal rates, I calculated that selenium concentrations in brine will be **2.04** and **2.96** mg/L in WTP #1 and WTP #2, and that its concentrations in the Pyritic TSF inflow will be **1.94** and **2.81** mg/L, respectively. Using these concentrations, I developed a simplified water balance model on a spreadsheet based on the KP model with their inputs for flows and chemistry, but substituting the above brine selenium concentrations as inputs. My spreadsheet model assumes that selenium concentrations in brine will remain constant regardless of their increase in influent, which is fed from the Main MWP. It does not correct for increasing salt concentrations in the WTP #2 inflow, which are expected to increase and impair selenium removal rates. Nonetheless, **this model predicts that selenium concentrations in the Pyritic TSF and in the Main WMP will gradually build up and increase by a factor of ten in the Main WMP by Year 6**. The model cannot be used to determine selenium increases past that time because additional interactions add uncertainty to expected removal rates.

The above finding flatly contradicts the assertion by Pebble that selenium concentrations will not build up in this closed water management circuit. Not only will selenium concentrations increase, they will reach concentration that overload the capacity of WTP #2 to meet the state discharge criteria for selenium. **As currently designed, the Alaska state limit of 0.005 mg/L for selenium will be exceeded in effluent of WTP #2 within 6 years of operation**. Given the sensitivity of wetlands downstream from the mine, it is almost certain to impact them.

Boron and Beryllium are likely to be removed via reverse osmosis (RO). The latter can also be removed by ion-exchange, but this process is unlikely to be as practical or economically-viable as RO.

Sulfate may be removed effectively by the combination of membrane filtration and calcium precipitation. Reviews of treatment technologies for sulfate removal considered membrane filtration as one among several promising technologies (INAP 2003, Boswell 2004). However, the treatment process proposed at Pebble has only been implemented *once* at full-scale (Hutton et al., 2009), so it cannot be considered a proven technology or an Industry Standard. It only became operational after considerable research and development work by Anglo American and this is likely to be the case at Pebble. The process has potential, but still requires more development (Aubé and Lee, 2015), and can only be considered a technology at an advanced stage of development.

4 Treatment performance

At the Pebble Mine, the importance and sensitivity of the downstream ecosystems gives very little tolerance for exceedances in regulated contaminants. If the performance from the treatment plants is not as good as predicted, there is a high likelihood of impacts. For this reason, I examined closely the performance predicted for the proposed treatment systems and evaluated the predicted removal rates against performances from known, operating treatment systems.

The fact that the USACoE proposes an unproven technology for selenium removal begs the question: how did they determine selenium removal rates? **How did they determine effluent concentrations for selenium, given that there is no commercial treatment plant relying on the chemical process they propose?**

If the predicted selenium concentrations in treated effluent are not validated by any case study or scientific report, then what about the predicted effluent concentrations for other constituents, which are similarly unsubstantiated by case studies or scientific reports. The effluent concentrations for a number of key analytes are exceedingly low and imply extraordinarily high removal rates, as shown in Table 2.

The removal rates in Table 2 are not substantiated in the FEIS by any testwork, literature or case studies. They appear to originate from modelling simulations rather than real-world experience. Given the well-known fact that metal removal becomes exceedingly difficult at trace levels, these removal rates are not credible. These predictions are even less credible when accounting for the salt buildup predicted within the water management circuit, as it is well-known that removal efficiencies are strongly affected by the salt composition of wastewater (e.g., Peng and Escobar, 2003). There is no indication that the removal efficiencies presented in Table 2 account for anticipated increases in salt concentrations. Therefore, they cannot be considered reliable.

Table 2. Predicted effluent concentrations and removal efficiencies for WTP#2 during mine operation.

Analyte	Influent concentration (mg/L)	Effluent concentration (mg/L)	Percent removal
Cadmium	0.01879	0.0000021	99.99%
Cobalt	0.054	0.00000236	99.99%
Copper	0.01	0.00000015	99.99%
Manganese	1.85	0.00075	99.96%
Mercury	0.000279	0.0000000007	99.9997%
Molybdenum	3.90	0.0017	99.96%
Selenium	0.041	0.000537	98.7%
Sulfate	1765	71.7	95.94%
Zinc	2.74	0.00002	99.99%

To test the validity of the predicted removal rates, I examined metal removal rates for reverse osmosis systems at other mine sites. A few operations have published removal efficiencies that are relevant to the present case. For instance, the reverse osmosis plant at the Canonsburg, Pennsylvania Uranium Mill Tailings Remedial Action Program (UMTRA) Site (MEND 2008) removes contaminants to low concentrations, but never with the removal efficiencies predicted at Pebble (Table 3). These data suggest that it is difficult to decrease metal concentrations significantly below 0.001 mg/L.

Table 3. Influent and effluent concentrations and removal efficiencies Canonsburg, UMTRA site.

Analyte	Influent concentration (mg/L)	Effluent concentration (mg/L)	Percent removal
Cadmium	0.076	0.01	8.68%
Copper	2.00	0.03	98.5 %
Iron	14.80	0.04	99.73
Manganese	1.61	0.02	99.76%
Radium	1.00	0.6	40%
Uranium	6.40	0.001	99.98%
Zinc	0.16	0.008	95%

Similar to the proposed Pebble WTPs, the eMalahleni water treatment plant uses a triple-pass reverse osmosis configuration (Hutton et al., 2009). It comes close to the same removal efficiencies as those proposed for Pebble (Table 4), but these efficiencies are for much higher initial concentrations. Effluent concentrations for metals do not come close to the trace levels predicted for Pebble.

There are other published reports of removal efficiencies for reverse osmosis (e.g., MEND 2014), but they do not provide operational data, including influent analyte concentrations, making it hard to evaluate.

Table 4. Typical influent and effluent concentrations for analytes at the eMalahleni water treatment plant.

Analyte	Influent concentration (mg/L)	Effluent concentration (mg/L)	Percent removal
Aluminum	40	<0.15	99.63%
Iron	210	<0.01	99.99%
Manganese	35	<0.05	99.86%
Sulphate	3090	<200	93.53%

These examples show that metals can be removed effectively by reverse osmosis, but that it seems difficult to decrease their concentrations significantly below 0.001 mg/L. Other factors, like water temperatures, the presence of other cations or antiscalants, compound this difficulty. **The predictions of metal removal to trace levels by the USACoE cannot be accepted without substantiation, especially considering the unsustainable claims they made regarding selenium removal. Such claims are only acceptable if supported by laboratory testwork, published literature or case studies for every contaminant.** Otherwise, the USACoE is asking us to accept their claims on faith, which is unacceptable.

5 Cation Accumulation in the Water Management Closed Circuit

I have already identified a problem with the accumulation of selenium in the water management closed circuit. There are other problems associated with this approach. Excess calcium and sulfate will be removed from mine water through RO, *but the performance of filtration membranes depends on the concentrations of other cations, such as sodium, potassium or magnesium.* Their concentrations increase markedly in brine and will increase in the water management circuit (WTP #2 Brine → Pyritic TSF → Main WMP → WTP #2 Brine) throughout the operation of the mine, along with calcium and sulfate (Knight Piésold, 2019). This will result in problems of scale formation in the mineral processing plant as well as the water treatment plant. Eventually, the performance of the RO units will degrade beyond the limits of the system because they were not designed for this type of water. Pumps will fail because the pressure on membranes will be too high, or membranes will experience breakthrough.

It is difficult to predict when exactly this breakpoint will occur, but it will certainly occur within the life of the mine. The problem of accumulating salts was previously raised in the DEIS and PFEIS and Pebble's response essentially says: *we will look at the problem when it happens*. This is naïve, unsatisfactory and cannot be disguised as Adaptive Management. This problem may require an expensive solution or, at worse, may be unsolvable.

6 Risk Assessment

Any complex treatment system contemplated by a mining company will undergo an internal risk assessment because it is critical to the operation (i.e., enable compliance with state laws). This is especially critical at the Pebble Project because of the sensitivity of the receiving environment and the potential risk to a world class fishery. Some of the key risks to consider with the proposed treatment system proposed by the USACoE are highlighted below, including:

- System complexity and scale
- Removal efficiencies/RO effectiveness at increasing salt concentrations
- Unconventional process for selenium removal
- Unconventional process for sulfate removal
- Resources for Research & Development
- Reliability and costs of treatment in perpetuity

6.1 System Complexity

The three treatment systems proposed in the FEIS are complex and very large, which makes them inherently risky. Different contaminants may require very different conditions for removal (i.e., pH/ORP during oxidation/iron precipitation), which will require additional new treatment steps. It is well-known that complex systems are inherently riskier than simple systems, increasing the risk of failure.

To some extent, the FEIS acknowledges this risk by building redundant treatment units in the plant designs. However, there is a great risk that a large and complex treatment system will not perform as intended when there has been no testwork or precedents (case studies) to support the design. Instead, the FEIS appears to rely on vendor literature, which is almost always excessively optimistic. Unexpected problems, such as problems caused by increasing salt concentrations in the water circuit, may lead to decreased performance and release of non-compliant water. In such a case, a correction would be very difficult and expensive because the problem of salt accumulation is built into the mine plan and system design.

There is an additional risk arising from the assumption of linear scaling of the proposed treatment system. This is an untested assumption that would normally be resolved through a rigorous test program. This was one of the issues with the eMalahleni water treatment plant that took three years to resolve (Hutton et al., 2009). The same experience has been reported for other, novel large-scale water treatment plants[4].

6.2 Removal effectiveness of reverse osmosis at increasing salt concentrations

The performance of filtering membranes in a nanofiltration or reverse osmosis unit is affected by ambient water temperature and salt concentrations. Almost always, their performance must be optimized through a pilot test program for a given mine water. However, the closed water circuit at Pebble (WTP #2 Brine → Pyritic TSF → Main WMP → WTP #2 Brine) adds new complexity and unpredictability to this issue because salt concentrations will be constantly increasing and evolving. This greatly increases the risk that WTP #2 will be out of compliance during mine operations, with no quick and easy solutions to resolve this (due to the ever-increasing salt concentrations inherent to this system design). The two analytes most at risk of falling out of compliance are selenium and sulfate because their concentrations may be increasing gradually and, in the case of selenium, because there is no remedy available to fix this problem.

6.3 Unconventional process for selenium removal

As indicated in Section 3, the treatment process proposed for selenium removal is unconventional. Although the chemistry for the chemical reduction of selenate/selenite to insoluble selenide via bisulfide has been demonstrated in the laboratory, those who have investigated this process have rejected it as a viable process for treatment of mine water.

Pebble's proposal to develop this process runs counter to this experience. They rejected the conventional process for biological selenium treatment and assert that they can develop by unproven process without providing any proof. There is a great risk that they will fail to develop such a process and their proposal should be viewed with great skepticism.

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[4] Alan Prouty, Vice President, Environmental & Regulatory Affairs, JR Simplot. Personal communication.

6.4 Unconventional process for sulfate removal

The need for removing sulfate from mine water is a relatively recent development in the mining industry, despite the fact that its concentrations in mining effluents are typically around 0.5-2.0 g/L. Dilution has typically been used to manage this contaminant but there is limited opportunity to use dilution at Pebble. Therefore there is a need to treat for sulfate.

Despite the existence of a number of processes for removing sulfate, only two processes have been used at mine sites: membrane filtrations and lime/calcium precipitation of concentrated sulfate. There's only one implementation of the process proposed by Pebble at an operating mine (Hutton et al., 2009). Overall, this process took 15 years to develop under more favourable conditions in South Africa[5].

There is a great risk that Pebble will not succeed in developing the process they propose for sulfate removal, that their removal rates will be less than predicted or that the development process will take much too long or cost too much, resulting in the discharge of non-compliant effluent. Given the long lead-time for developing the process at the eMalahleni water treatment plant, there is a significant risk that the mine will be out of compliance for a prolonged period during its operations. The problem is even more acute at closure because there will be fewer resources available to remedy this problem.

6.5 Resources for Research & Development

Most unconventional treatment systems take many years to develop and require significant investment in R&D. This was the case for the eMalahleni water treatment plant (Anglo American), the reverse osmosis/HDS plants at Yanacocha (Newmont), and the biological treatment plants for selenium at Smoky Canyon (J.R. Simplot) and West Line Creek and Fording River coal mines (Teck Coal).

All of the above mining companies have the resources to support the necessary R&D work and most of them have their own research facilities (e.g., Teck's Applied Research and Technology Center) with specialized equipment, scientists and technical staff. Northern Dynasty has none of these, nor does it have the capitalization necessary to support such development work. This casts doubt on their ability to conduct the R&D necessary to develop their proposed water treatment systems. **Northern Dynasty's claims are very optimistic but they are not in a position to deliver.**

6.6 Reliability and costs of treatment in perpetuity

The ideal of closing out a mine and walking away is never attained. Typically, closed mines continue to discharge contaminated water for a long time and require treatment, often in perpetuity. Simple treatment systems, like the High-Density Sludge (HDS) process are easy to design, operate and maintain for the long-term, but we have no experience with the long-term operation of large, complex systems such as

[5] The colder ambient water temperatures in Alaska carry a higher risk of undesirable side-reactions, such as the precipitation of reactants on the walls of reactors, which will impair their performance.

proposed in the FEIS. Their long-term performance in such a remote region of the world is highly uncertain, which presents a significant risk of failure.

Compounding this uncertainty is the significant problem of paying for the operation and maintenance of such a treatment system for 200-10,000 years. This cost will easily exceed $1 billion and could run in excess of $3-4 billion. There is a high risk that the Northern Dynasty will not be able to meet its long-term obligations and default, leaving the people of Alaska to bear this burden[6].

7 Conclusions

The proposed Pebble Mine is located at the headwaters of Bristol Bay, which supports a world class salmon fishery. Additionally, there are numerous wetlands that support large bird populations downstream from the mine. The sensitivity of these ecosystems requires that the mine treats its effluents to a very high quality. There is virtually no tolerance for deviation from stringent water quality criteria, since there is little dilution to decrease contaminant concentrations. This presents a great challenge to the Pebble Limited Partnership (PLP). **My assessment of their proposed water treatment schemes is that they fail to meet these standards.**

Each of the three water treatment plants (WTP) proposed in the FEIS are large, complex, and rely on some unproven technologies. This alone makes their performance uncertain, a risk that is compounded by the fact that their design is not supported by testwork, scientific and technical literature, or case studies. Considering the large number of contaminants that must be removed and their exceptionally high removal rates, I disagree with the FEIS conclusion that the water treatment scheme will mitigate risks to the environment by producing high quality water. On the contrary, this is a high-risk design for challenging water, it does not represent industry standards and its performance is premised on wildly optimistic assumptions. My own analysis indicates that it will produce non-compliant water within the life of the mine. Given the sensitivity of the receiving environment, this proposal represents an unacceptable risk.

Most of the design for the proposed WTPs is unsubstantiated by testwork, scientific and technical literature, or case studies. This is an unacceptable standard in any of the jurisdictions where I have worked professionally and it should never be acceptable in an advanced country like the USA.

The USACoE states that compliant water treatment will be achieved by using "*processes commonly used in the mining industry around the world*". This statement is demonstrably false. The treatment process for selenium removal is unproven and is not used anywhere in the mining industry. In fact, the biological treatment process originally proposed in the DEIS, which is the current industry standard, has been substituted by this unproven process that will not remove selenium effectively. Additionally, the process

[6] As essentially happened at the Faro Mine, in the Yukon.

for sulfate removal can best be described as a technology at an 'advanced stage of development' rather than a proven technology, let alone an industry standard. It still required further research to prove that it can perform effectively and reliably under all conditions experience at Pebble. There is no guarantee that conditions such as low water temperature will allow it to perform with the same effectiveness as the eMalahleni plant in South Africa. On that basis alone, there is considerable doubt about the treatment effectiveness for these two contaminants, among others.

My analysis of the previous DEIS identified several problems that needed resolution (Sobolewski, 2019). Only two of these issues have been remedied. The design has been made more conservative by adopting 90th percentile values as a design basis and by adding redundant treatment units. Additionally, a heat exchange system has been added to conserve heat within the system and to lower effluent temperatures. Several other problems have been left in place or made worse, casting doubt about the effectiveness of the proposed treatment system.

A significant design change from the DEIS proposal is the elimination of a biological treatment unit for selenium removal and its replacement with a two-stage chemical precipitation process. **This change cannot possibly be justified on any grounds.** The co-precipitation of selenium with iron is a well-established process. It is described incorrectly (HDR, 2019) as requiring an oxidative step, when in fact it requires a reductive step. The process has been reported to produce effluent containing selenium concentrations of 0.012-0.022 mg/L (Alberta Environment, 2005), which exceeds state standards. The follow up process, the chemical precipitation of dissolved selenium into a selenium sulfide has never been implemented at any operating mine in the world. This proposed chemical precipitation process is not credible. **PLP needs to explain why it decided to substitute a process which is known to be effective (biological treatment) for another which is unproven and demonstrably inapplicable at operating mines.** Their credibility is even more questionable when they predict very low effluent selenium concentrations, when there is no testwork, no literature support and no comparable treatment system to support their claim.

I evaluated the likely fate of selenium in the water management circuit during mine operation. In this evaluation, I used defensible assumptions (presented in my analysis), as well as the Water Quality model developed by Knight Piésold, to assess the build up of salts in the Main WMP. I concluded that selenium concentrations will gradually increase in the closed water management circuit (WTP #1/#2 Brine → Pyritic TSF → Main WMP → WTP #2 Brine) until they exceed 6 mg/L by Year 6 of operation. **At that time, selenium concentrations in the discharge of WTP #2 will exceed the Alaska state limit of 0.005 mg/L, impacting downstream environments, especially shore and waterbirds foraging and reproducing in wetlands below the mine.** There is no doubt that these impacts will be the result of the decision by PLP to substitute the biological treatment system from the chemical process presently proposed in the FEIS.

The effluent concentrations for metals from the RO units from WTP #2 during mine operation are predicted to be exceedingly low, resulting from extremely high removal rates (Table 2). These claims are not substantiated by any testwork, scientific and technical literature or case studies. Although one case study shows comparable removal rates for a few analytes, the comparison is not applicable because of differences in starting concentrations (Table 4). Other examples show that reverse osmosis never attains the very low contaminant concentrations predicted in the FEIS. I conclude that the predicted effluent water quality is overly optimistic. Additionally, the gradual increasing concentrations of salts during mine operation (Knight Piésold, 2019) will impair treatment efficiency for the RO units. **I conclude that Pebble is proposing a water treatment system with an unrealistic treatment performance and unattainable effluent concentrations for regulated contaminants. Treatment efficiency will deteriorate gradually, increasing the risk of impacts to aquatic ecosystems.**

This problem of salt buildup could be remedied by including a salt removal step, for example by installing an evaporator/crystallizer unit in all the WTPs. Such a unit has only been proposed for WTP #3 during Phase 1 of closure. An evaporator/crystallizer unit should have been included in the design of WTP #2 to prevent the build up of salts during operation, though it would greatly increase its capital and operating cost.

The multi-pass RO system proposed by Pebble has very few precedents at other operating mines. One of them is the eMalahleni water treatment plant. The latter system was designed to treat acid mine drainage and maximize water recovery, while producing potable water. A review of the eMalahleni treatment system states that it took 15 years to develop from concept to startup of the full-scale plant. This timeline is unrealistic for the Pebble Project. Significantly, the development process was supported by Anglo American, a company with far greater financial resources than Northern Dynasty. Additionally, the plant operates in South Africa, where sulfate removal from warm water is easier than in the cold water at Pebble. It is likely that developing the proposed sulfate removal process at Pebble will be challenging and will tax the resources of Northern Dynasty Minerals. It is unacceptable to propose in a FEIS such a complex, technically-challenging treatment system without showing how PLP will bring it into full operation when it is needed.

In general, the R&D effort necessary to develop the treatment plants proposed in the FEIS will take several years and is beyond the capabilities of Northern Dynasty Minerals. There is a significant risk that they will not be ready to operate by the time they are required for mine operation or that they will perform as effectively as predicted in the FEIS. The mine should not be permitted until Northern Dynasty Minerals demonstrates convincingly how it will support this development process.

RFI 021e asked for an explanation of the anticipated buildup of salts and selenium in the water management circuit. HDR, the engineering firm that designed the proposed treatment systems, responded to the question of selenium buildup incorrectly because they assumed that sulfide precipitation would remove selenium completely, an unsubstantiated assumption. I demonstrated that selenium concentrations in the Pyritic TSF and Main WMP would increase to ~6 mg/L within 6 years, resulting in the production of non-compliant effluents. Additionally, I indicated that the buildup of soluble salts will impair the treatment performance of RO units in WTP #2. **HDR's lackadaisical response to RFI 021e**

regarding the impacts of increasing salts reflects a poor understanding of membrane filtration systems. This decreases considerably my confidence in their overall system design, especially since it is largely unsubstantiated by testwork, literature or case studies.

Several risks were identified, including:

- Risk of ineffective performance due to system complexity and scale
- Risk of decreased removal efficiencies/RO effectiveness at increasing salt concentrations
- Risk from unconventional process for selenium removal
- Risk from unconventional process for sulfate removal
- Risk from insufficient resources for Research & Development
- Risk of failed treatment performance from unreliability and costs of treatment in perpetuity

In my opinion, the greatest risk to this project is the problem of long-term treatment at Pebble. Accepting Pebble's proposition that it can treat water in perpetuity assumes that the company will become wildly successful and able to cover the $1-4 billion necessary to operate and maintain their proposed treatment systems for 200-10,000 years. I have heard often similar claims in my 30 years of experience with the mining industry, but have rarely seen them substantiated. Northern Dynasty's claims beg disbelief and should be viewed with deep suspicion.

In conclusion, the water treatment system presented in the FEIS is complex and unproven and presents a high risk of causing impacts to the sensitive ecosystems downstream from the proposed mine. It should be flatly rejected.

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